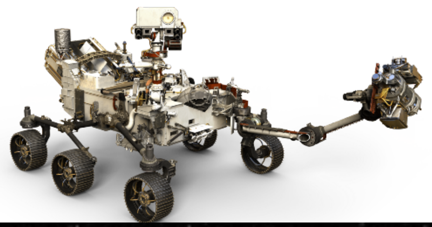
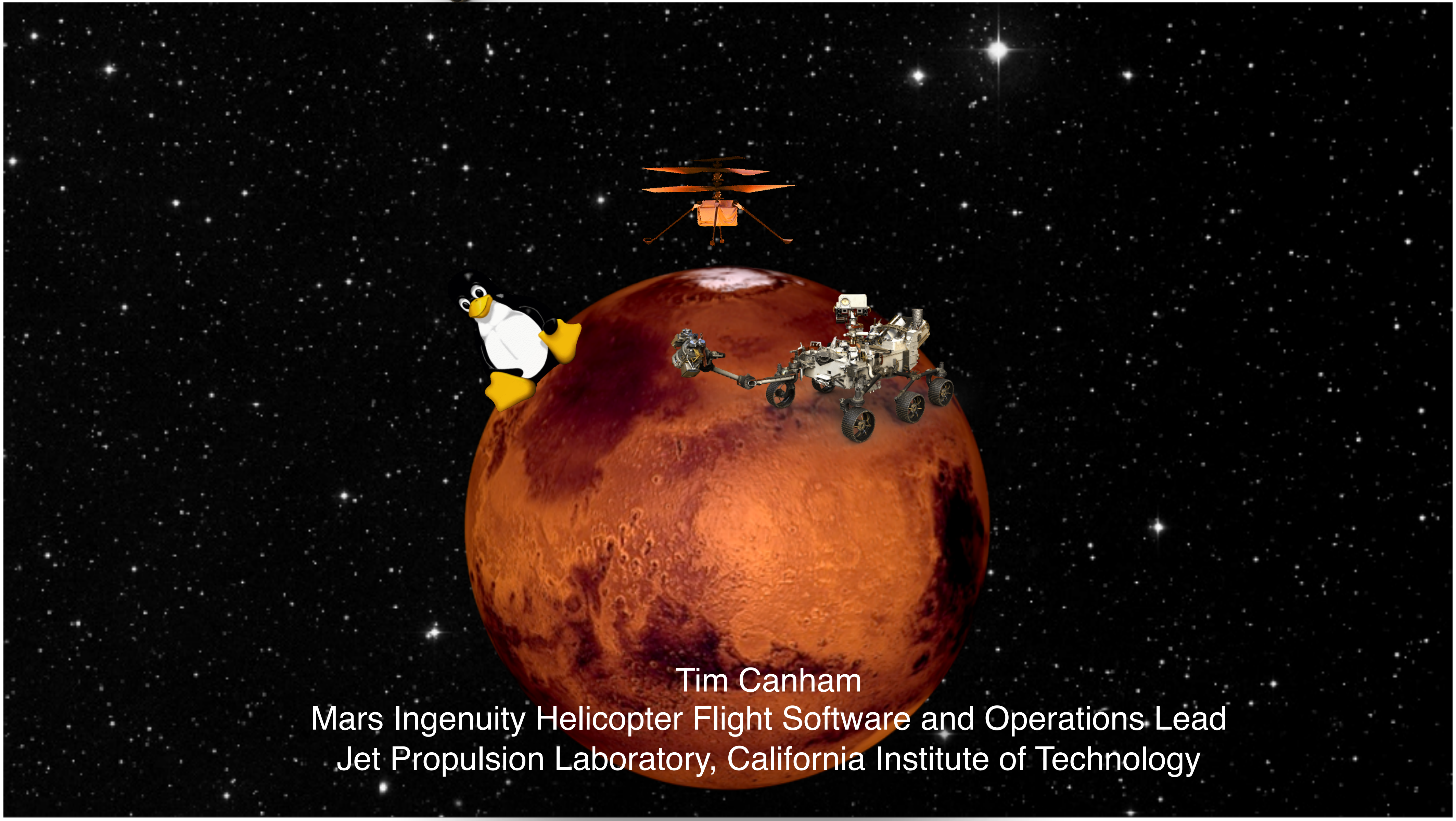
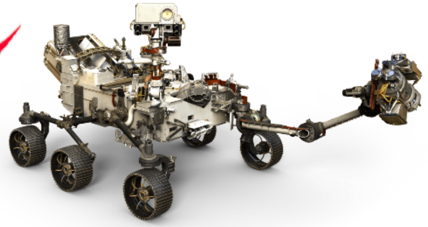
Jet Propulsion Laboratory
California Institute of Technology



Linux on Mars

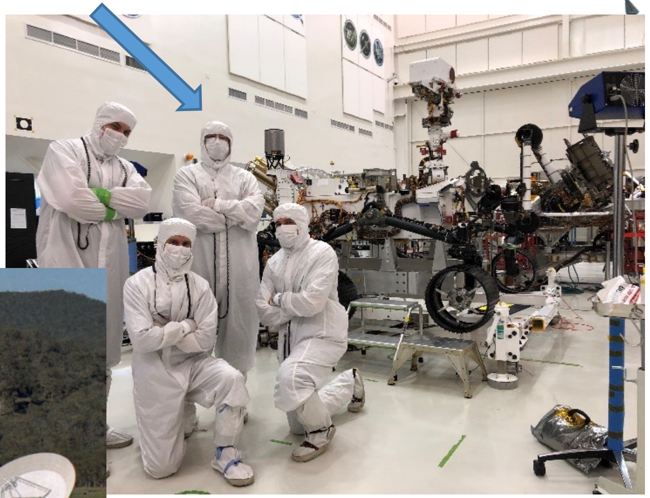


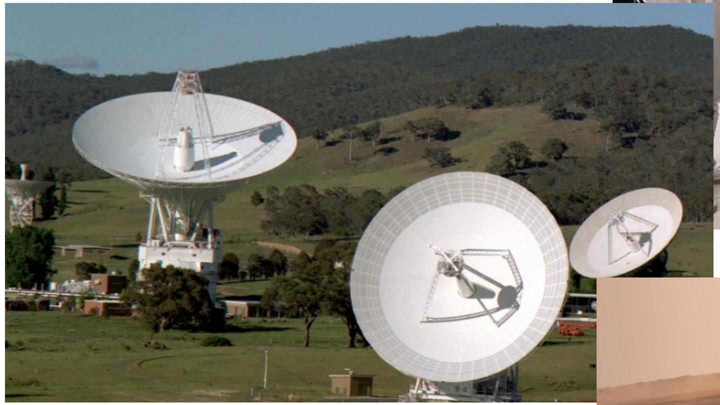
Tim Canham
Mars Ingenuity Helicopter Flight Software and Operations Lead
Jet Propulsion Laboratory, California Institute of Technology

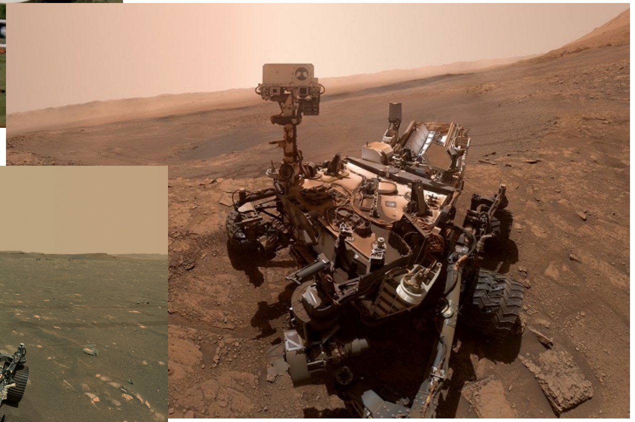


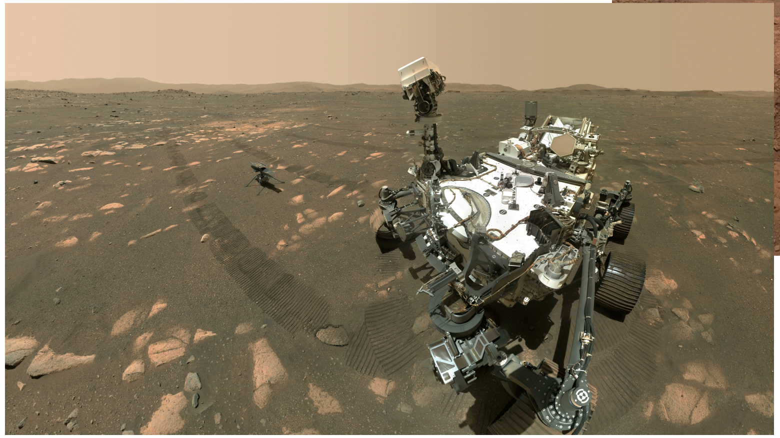
Who I am

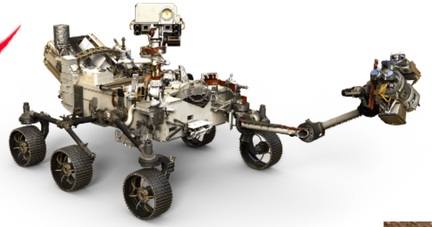
- Senior Software Engineer at NASA's Jet Propulsion Laboratory
- Projects
  - Deep Space Network
  - Cassini
  - Curiosity
  - Ingenuity
    - FSW lead
    - Operations lead
- Architect of F Prime
- Helped advance Linux at JPL



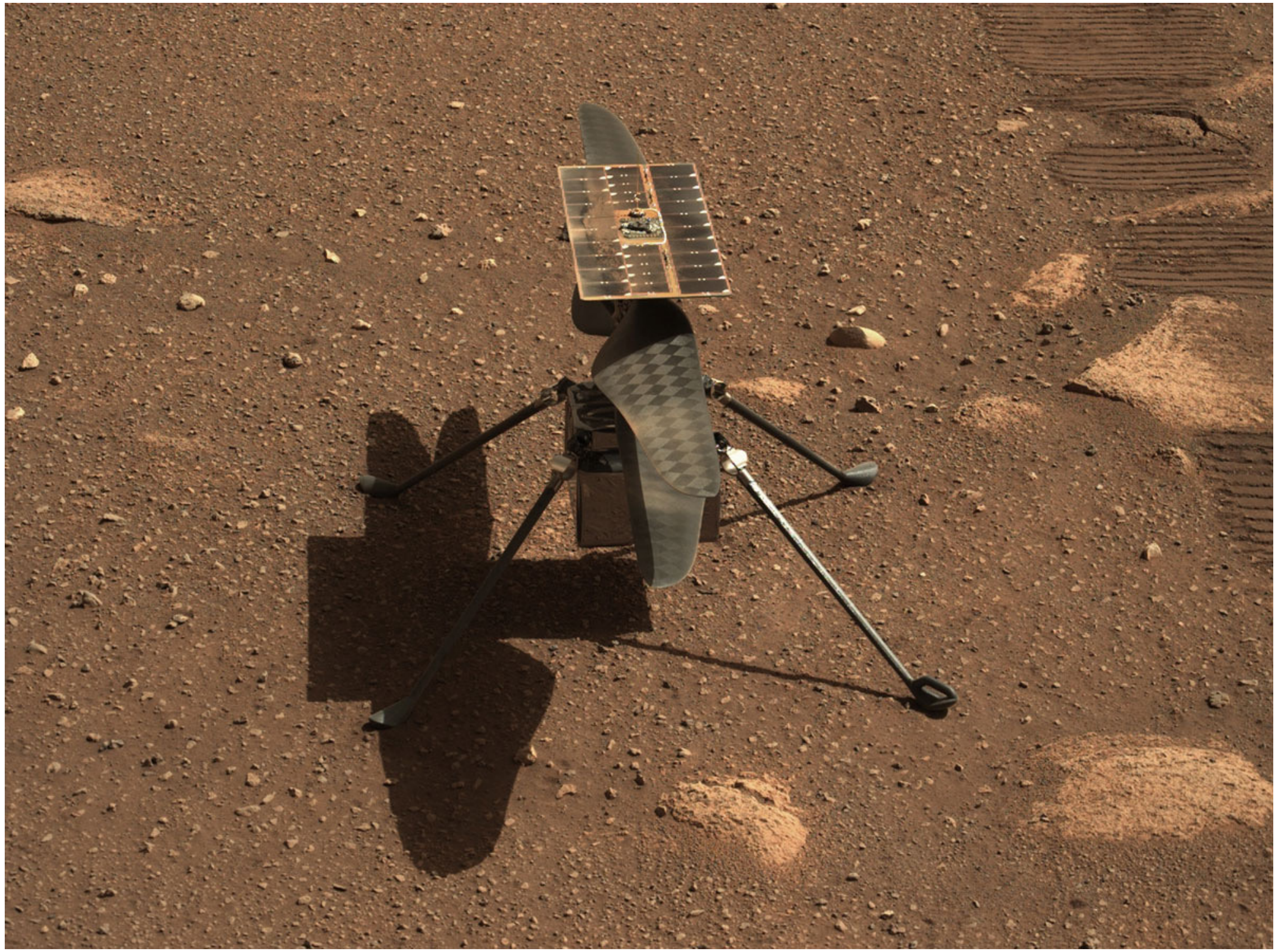


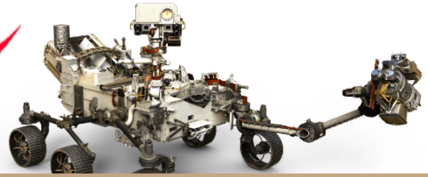




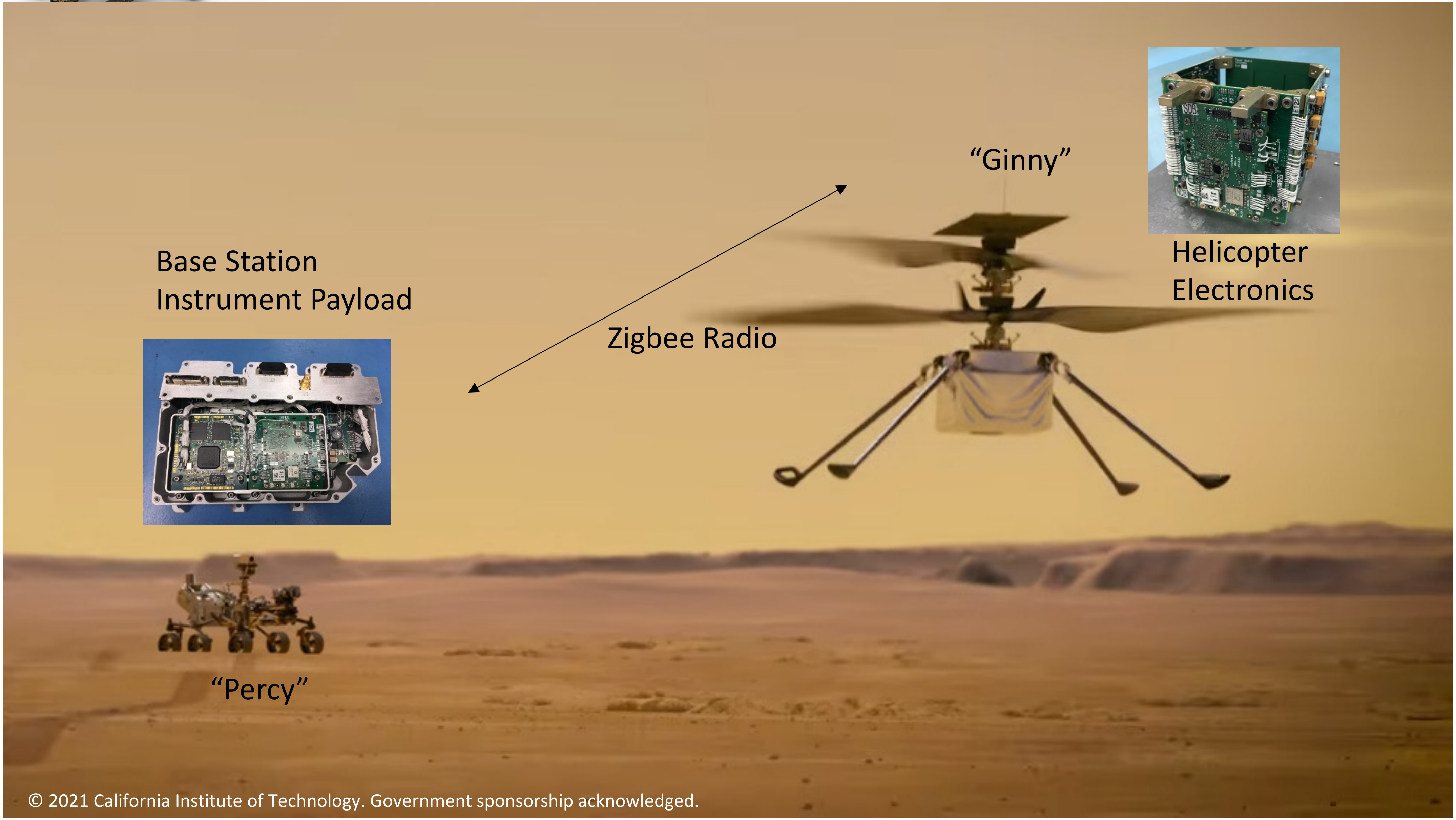


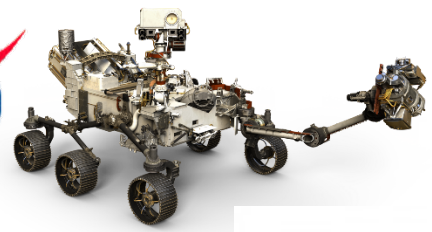
Ingenuity Mars Helicopter



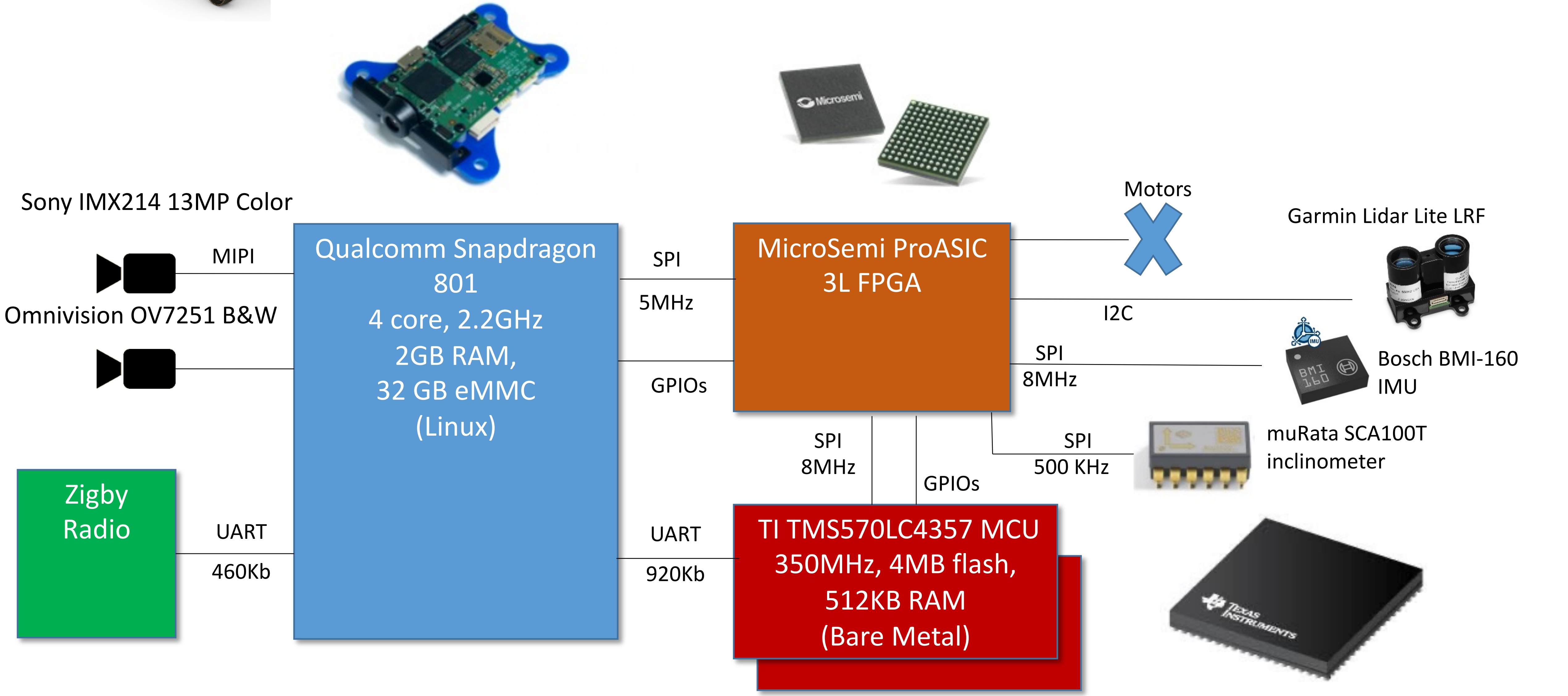


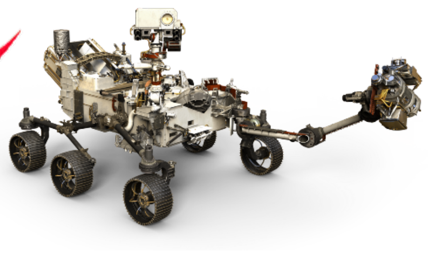
Mars Helicopter System





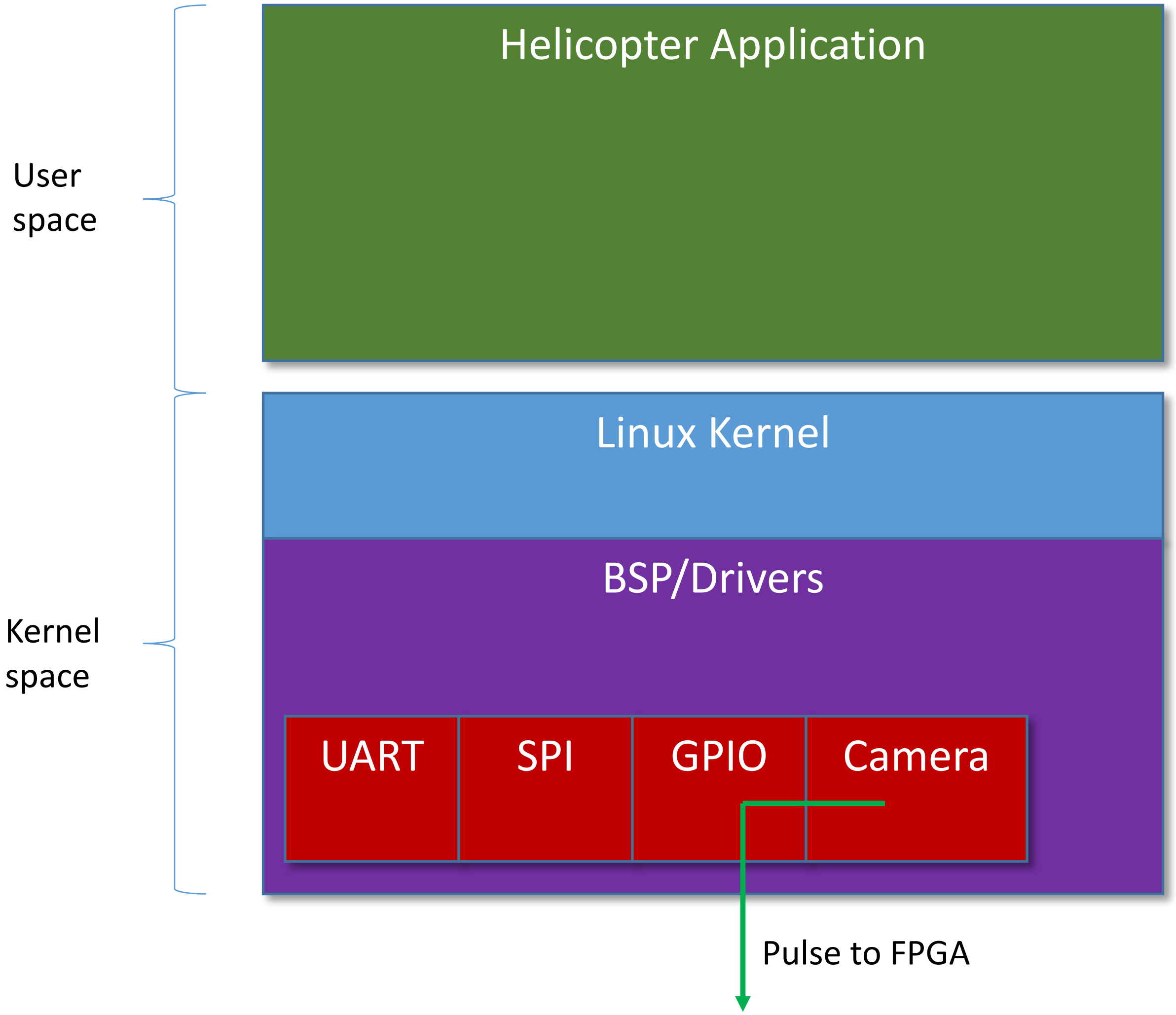
Mars Helicopter Block Diagram

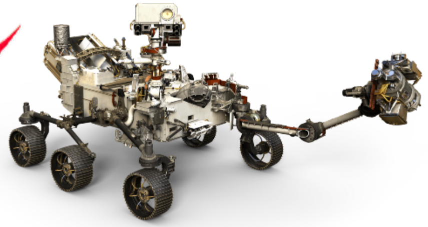




Mars Helicopter Operating System and Software

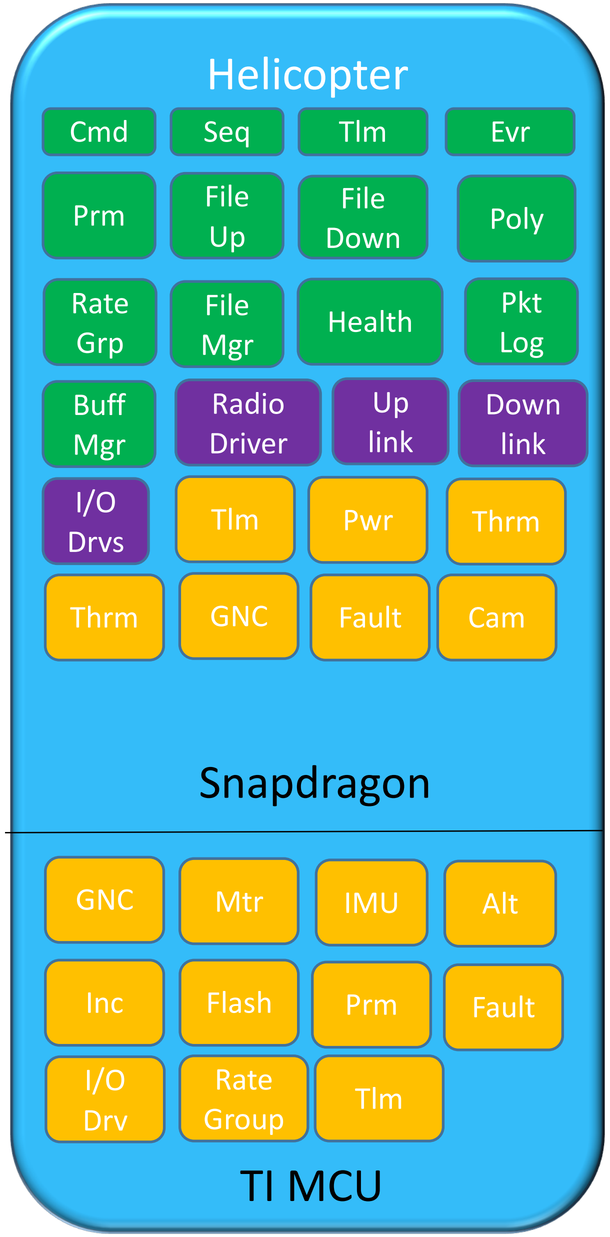
- Linux
  - Linaro 3.4.0
  - Linux/Android hybrid
  - PREEMPT patch (No RT patch!)
  - BSP provided by Qualcomm/Intrinsyc
  - Camera drivers included with BSP
    - Modified to "pulse" camera interface with FPGA to time-stamp images
  - Linux kernel driver interface for I/O in BSP
  - Helicopter application is fully userspace
    - Runs as root

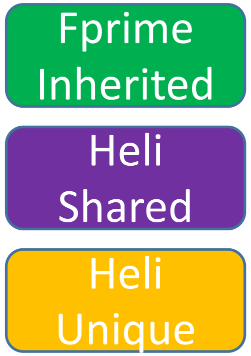


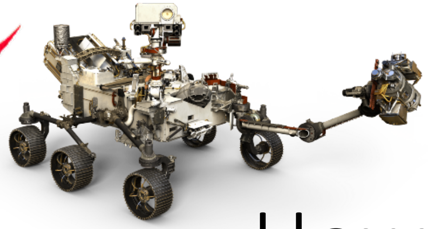


Helicopter Application

- Uses F Prime open-source flight software framework
  - https://github.com/nasa/fprime
- Tinker-toy style component architecture
- Inherits code from previous JPL missions
- Shares code internally
- Broadcasts real-time data via radio and stores higher rate telemetry to file after each flight
- 6 redundant copies with checksums started by upstart scripts

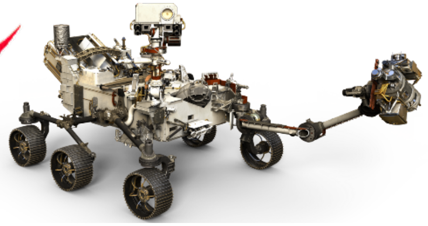




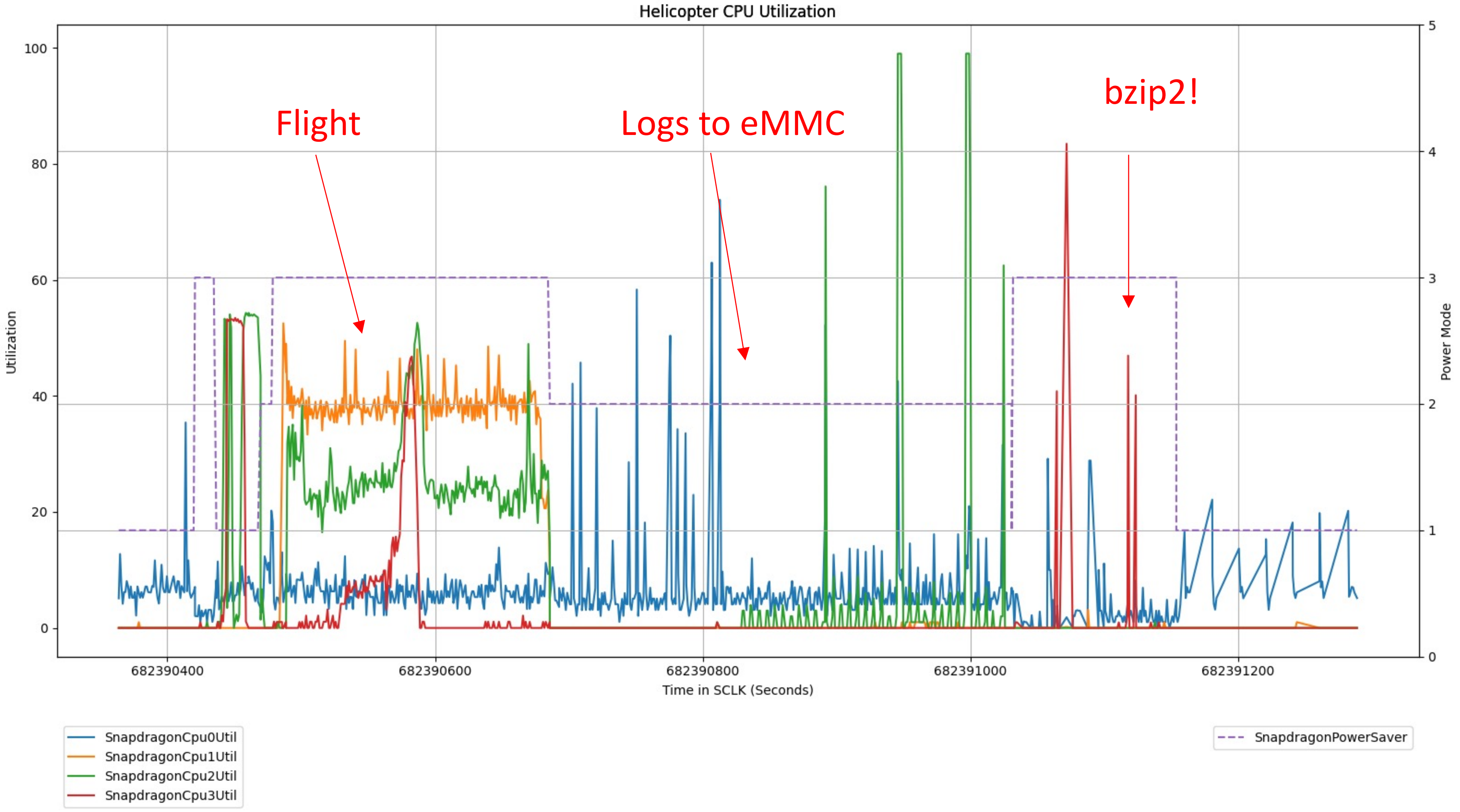


How do we use Linux besides the application?

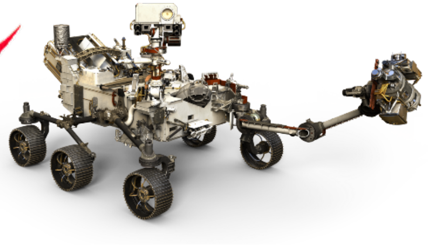
- We have a command to invoke arbitrary commands on the Linux command line.
  - Uses stdlib system() API call
- We have used it to:
  - Compress log files (bzip2)
  - Checksum files (md5sum)
  - List files (ls)
  - Remove older files (rm)
  - Run bash shell for various cleanup tasks
- Use "taskset –c" to select which core to use



How busy is the system?

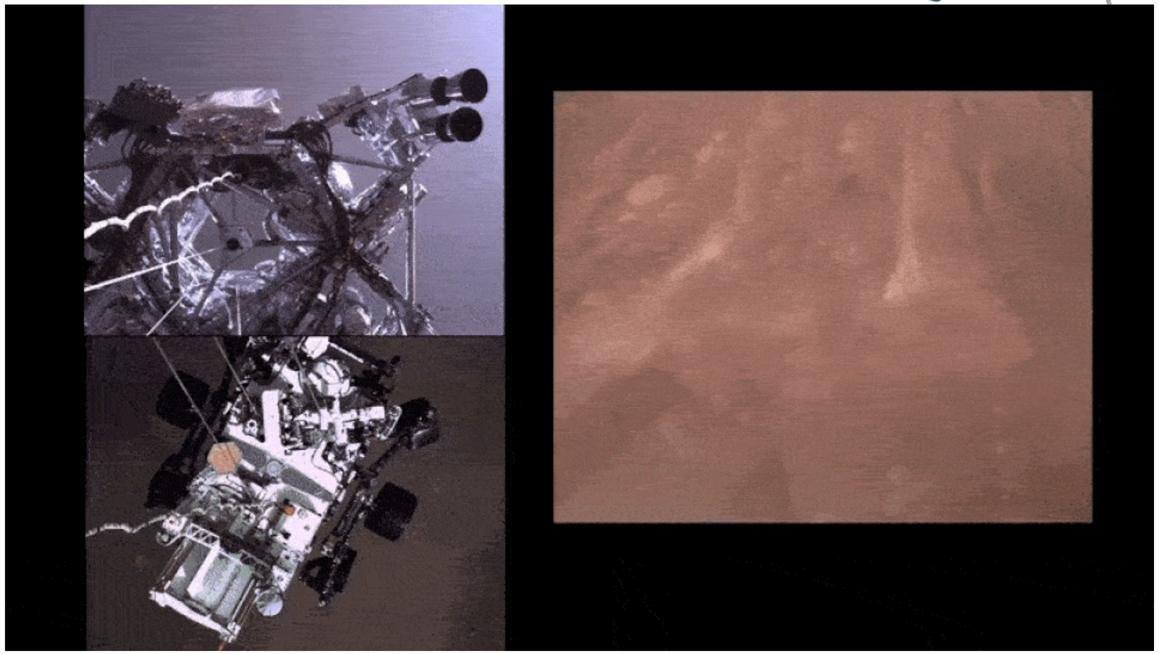


- Core 0
  - Data handling and logging
  - Telecom
  - Device I/O
- Core 1
  - Cameras
- Core 2
  - Visual processing
  - Image logging
  - Data routing to MCU
- Core 3
  - Guidance/Naviga-tion processing



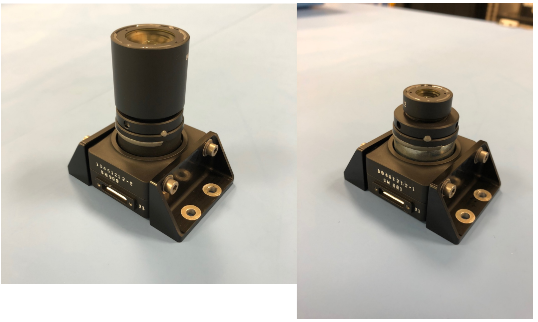
Perseverance Rover EDL Cameras

- Perseverance Rover also had Linux-based landing camera system
  - Not involved in guidance, just recorded landing
- Ruggedized Intel Atom PC
  - More like a conventional PC
- USB cameras
  - USB cabling with hubs throughout vehicle
  - FTDI to rover interface UART
- Linux x86 kernel 4.15.7
- Used much open-source including ffmpeg and Python



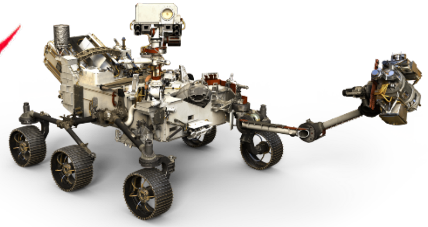
Computer

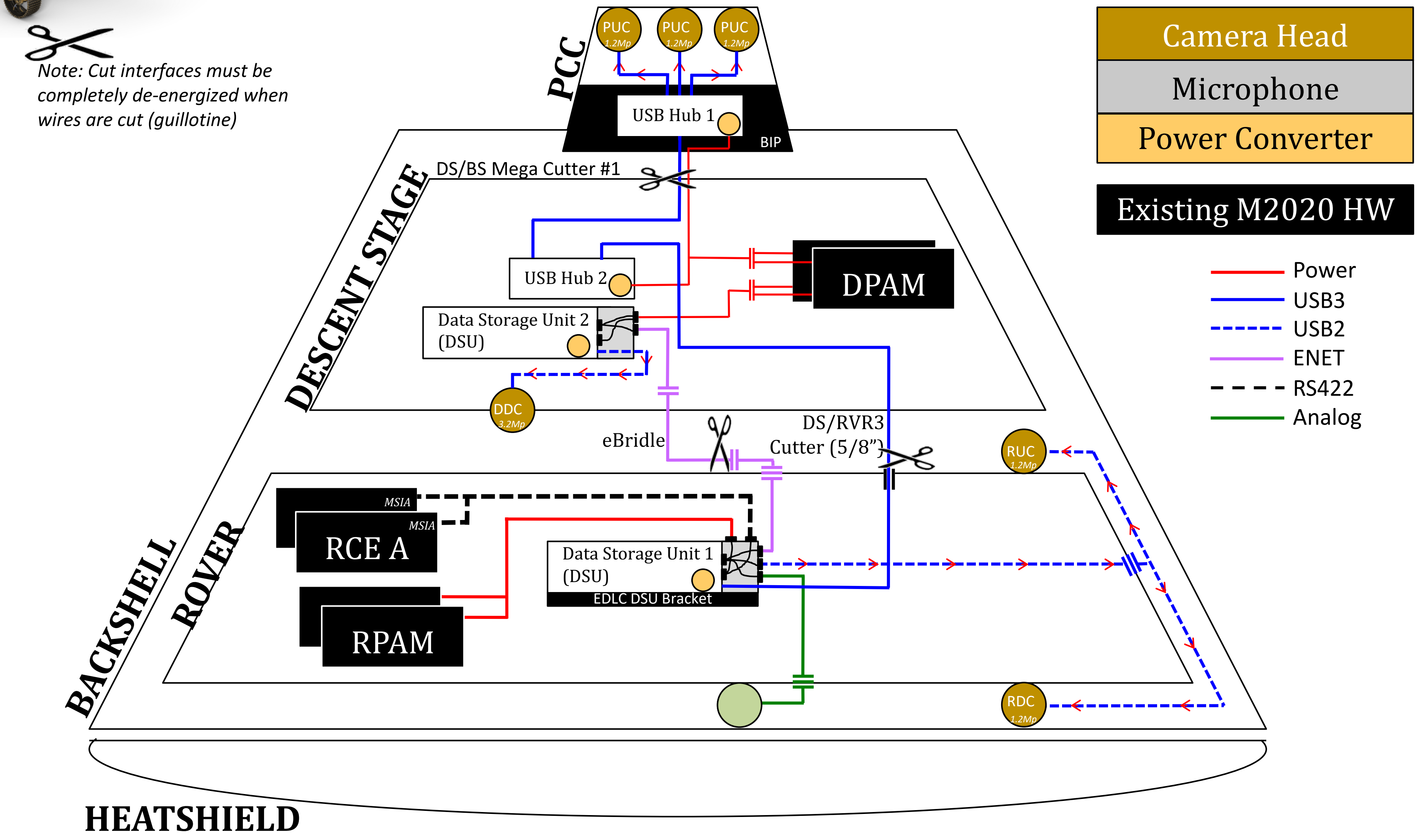
USB Hub

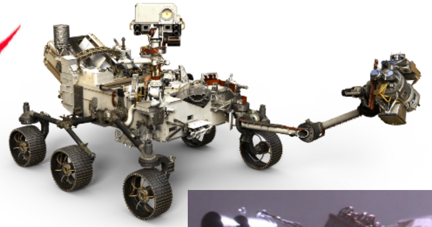


USB Cameras

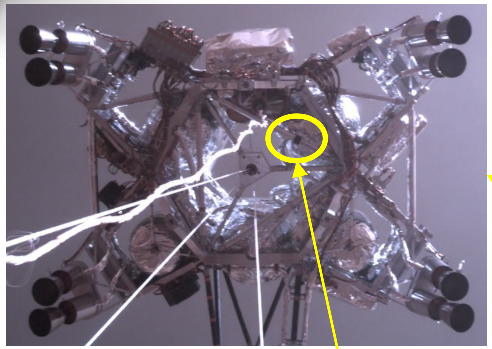
EDL Camera Functional Block Diagram



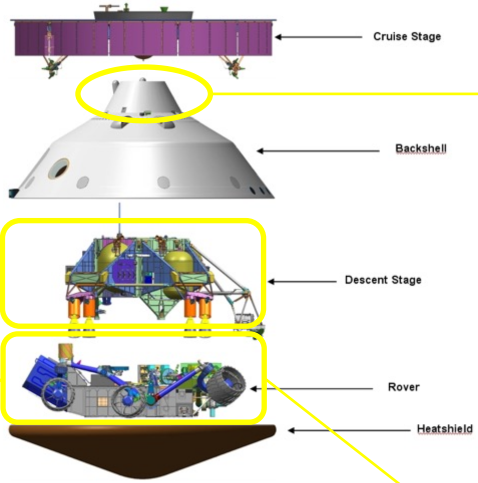


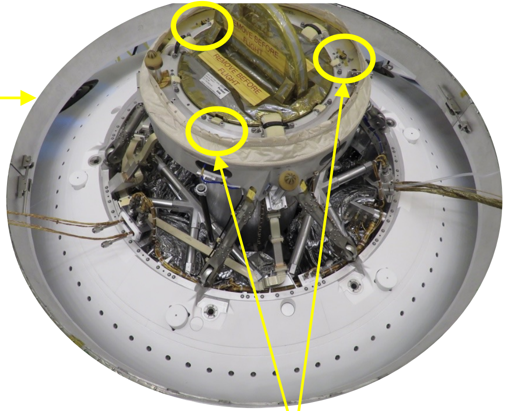


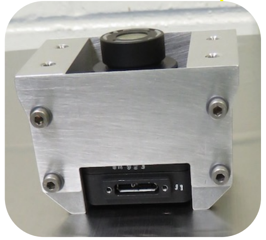
EDLCAM Sensors



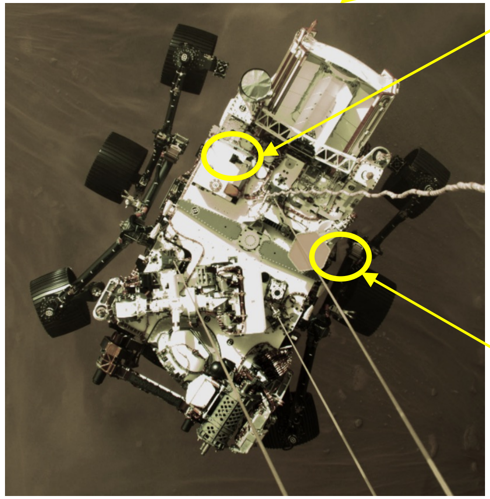
Descent Stage Downlook Camera (DDC)



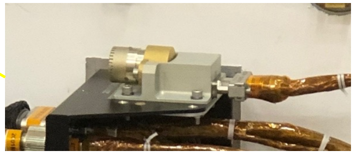




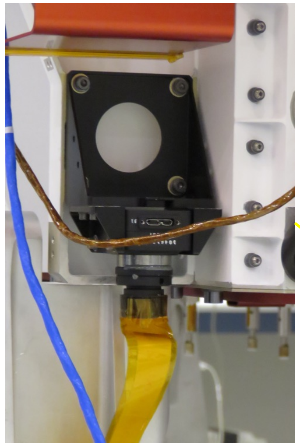
Parachute Uplook Cameras (PUC x3)



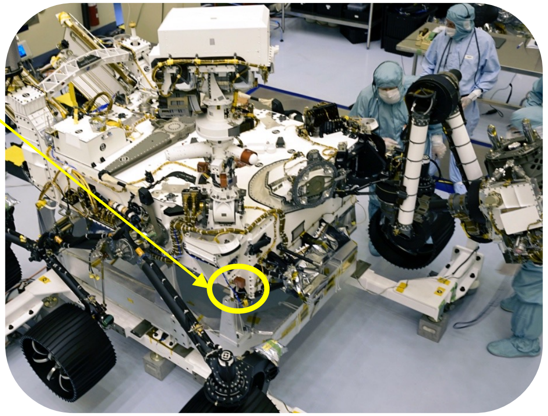
Rover Uplook Camera (RDC)

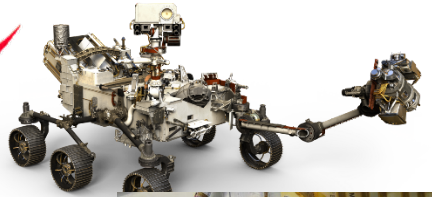


Microphone Capsule

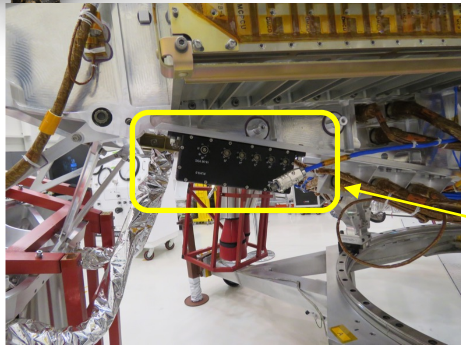


Rover Downlook Camera (RDC)

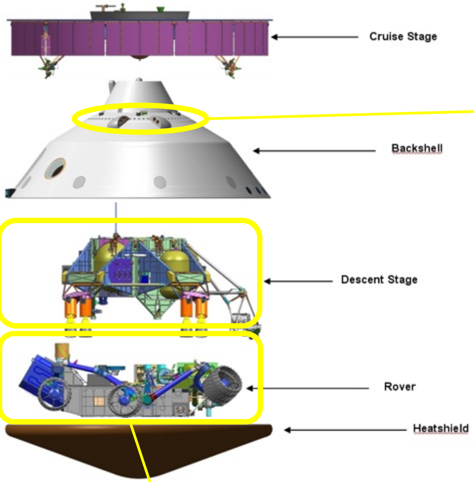


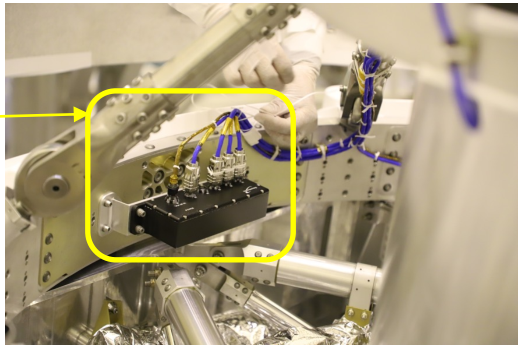


EDLCAM Support Hardware

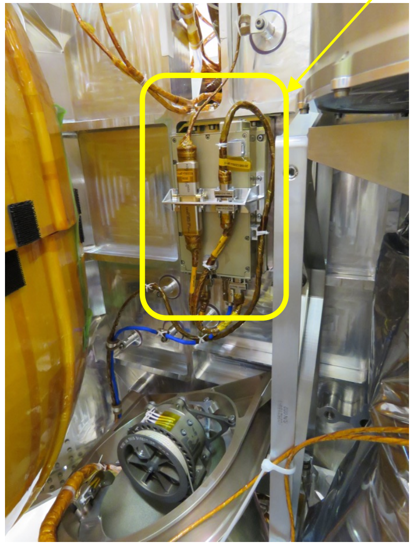


Descent Stage
Mounted USB Hub

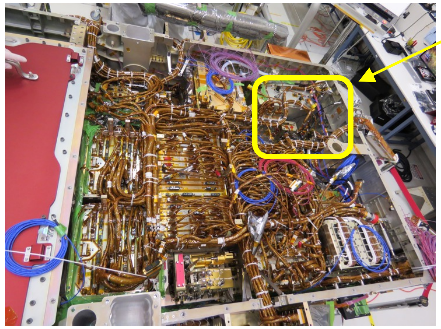


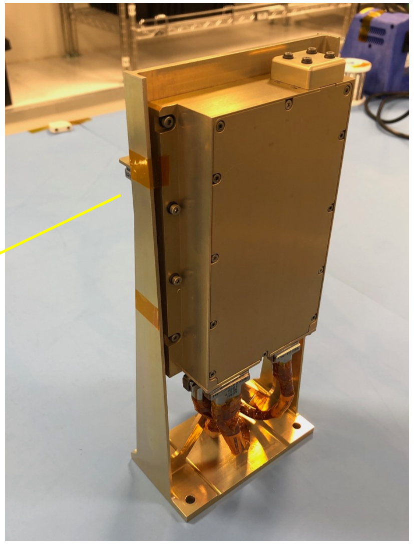


Backshell Mounted USB Hub

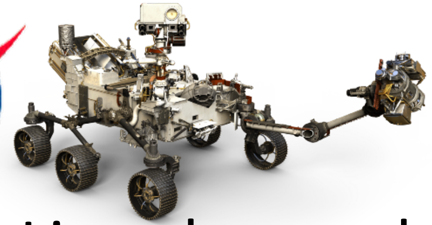


Descent Stage Data
Storage Unit





Rover Data Storage Unit



Conclusions

- Linux boosted our ability to develop quickly
  - We had standard I/O drivers
  - Manufacturer BSP was available
  - Shell/adb interface made testing much easier
  - COTS facilities like Wi-Fi, USB and standard I/O made test support equipment *much* easier
  - Allowed early prototyping on other platforms like Raspberry Pi
- Linux did very well, as long as you were aware of its limitations
  - Not real time, so built in robustness to slips
    - RT patch probably would have been better, but not available on our kernel
  - Avoid file I/O during performance critical times
  - Build in file-system level protections (ex. read-only partitions for software/Linux executables)
- Future of Linux in space exploration is rosy!